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Statistical analysis of patent data relating to the organic Rankine cycle

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ABSTRACT

This study analyzed patent data to explore the technological developments based on the organic Rankine cycle (ORC), which is one of the most economical and efficient methods for converting low-grade thermal energy into electricity. The patent data were obtained from the Thomson Innovation commercial database, which contains patent information from various countries and offices. After querying, filtering, and organizing the results into patent families in accordance with International Patent Documentation Center guidelines, this study analyzed data on 304 ORC-related patents. The results show that the number of patent applications increased gradually before 2006, and then rapidly from 2009 to 2011, primarily because of contributions from patent applications in China (CN) and the Republic of Korea (KR). The present findings indicate that 2009 is an important year regarding developments in ORC systems and the number of patent applications. Furthermore, the assignees from the United States (US) were the most prominent contributors. However, the most patent applications were filed in CN, indicating that the market for ORC systems in CN might offer the most potential for future development. This study also examined the top ten patent assignees, as well as the trends of the number of patent applications, size of patent families, and frequency of patent citations. The results show that all of the top ten assignees were from the US, CN, and KR. Moreover, most of them filed their patent applications in recent years, particularly after 2008. The results further indicate that the most active assignee is currently General Electric Company (US). In addition, the top five patent families and the five most frequently cited patents are briefly reviewed and discussed. The patent data analysis results indicate that the technology life cycle status of the ORC is currently in the growth stage.

Contents

1. Introduction

In principle, an organic Rankine cycle (ORC) is identical to the steam Rankine cycle, except it involves using organic fluids with

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a low boiling point as a working fluid to generate power from low-temperature heat sources [1]. The ORC is considered one of the most economical and efficient methods for converting low-grade thermal energy, such as geothermal energy, solar thermal energy, waste heat recovery, biomass energy, and ocean thermal energy, into electricity [2,3]. Recent studies on the ORC have applied various perspectives and research tools, including conducting technical–economic–market surveys [1,4], developing methods for selecting working fluids [5], evaluating waste heat recovery from a power plant [6], onboard ships [7], and at data centers [8], as well as proposing proof-of-concepts [9], optimal control strategy models [10], quasi-dynamic models [11], assessing the effect of optimal pinch point temperature range of evaporators on system performance [12], prototype testing [13], and off-design performance analysis [14].

Quoilin et al. [1] conducted a techno-economic survey of ORC systems. They performed a market review based on various factors, including cost figures of several commercial ORC modules and manufacturers. Regarding technical challenges, they indicated that working fluids and expansion machines are two key aspects of ORC technology. In addition, they showed that state-of-the-art ORC units are typically designed for nominal operating points. Consequently, they perform poorly under off-design conditions. Vélez et al. [4] provided an overview of the technical and economic aspects, as well as the evolution of the ORC market for converting low-grade heat to generate power. They reported that the ORC capacity from the available providers was typically limited to 0.2–2.0 MWe, costing approximately €1000–€4000/kWe. Bao and Zhao [5] reviewed methods for selecting both pure and mixed working fluids used in ORC systems. They concluded that heat transfer characteristics, flammability, and material compatibility are key parameters involved in selecting pure working fluids, whereas thermal physical properties and heat transfer characteristics were considered the most crucial parameters for selecting mixed working fluids.

Gewald et al. [6] evaluated the waste heat recovery of the Ano Liosia gas-fired power plant in Greece to improve its productivity and efficiency in generating electricity. They proposed two waste heat recovery cycles (the water/steam cycle and ORC) for the power plant based on a detailed thermodynamic cycle simulation and economic evaluation. Aghahosseini and Dincer [9] analyzed the performance of a low-grade heat source ORC system that used both pure and zeotropic-mixture working fluids. They reported that the system efficiency increased in conjunction with both the expander inlet pressure and boiling point temperature of the working fluid. In addition, they showed that when the working fluid was superheated, the energy efficiency of the system remained almost constant but the exergy efficiency decreases.

Manente et al. [10] proposed an off-design model of an ORC system for identifying optimal control strategies. They argued that the optimal maximum pressure of the ORC system can approach the critical pressure level during both subcritical and supercritical cycles, but the optimal operation strategies for subcritical and supercritical cycles differ. Bamgbopa and Uzgoren [11] proposed a transient modeling approach for an ORC system operating under various heat input conditions. They investigated the transient mode of ORC system operation, and they reported that heat exchangers (i.e., the evaporator and condenser) are key system components because ORC systems are based on heat-to-power conversion processes. Li et al. [12] showed that the optimal pinch point temperature difference of the evaporator was approximately 13 °C, whereas that of the condenser was approximately 17 °C. Moreover, various organic working fluids facilitated the maximal net power output per unit area of heat transfer under pinch point temperatures similar to that of the evaporator. In addition, they showed that the optimal pinch point temperature difference of the evaporator decreased in conjunction with the pinch point temperature of the condenser.

Lee et al. [13] studied the influence of various evaporators on the response of an ORC system. They reported that the effect of heat source flowrate of the evaporator on the transient response of the ORC system was negligible, indicating that the flow rate of the heat source should be minimized to maximize system efficiency. In addition, they showed that the effect of the evaporate exit superheat on the ORC system depends on the type of evaporator. For a plate evaporator, superheat less than 10 °C may result in an unstable ORC system. However, for a shell-and-tube type evaporator, no unstable oscillation of the ORC system was observed when the exit superheat was between 0 °C and 17 °C. Fu et al. [14] analyzed the effect of off-design heat source temperature on the heat transfer characteristics and system performance of an ORC system. They showed that a higher heat source temperature yielded better heat transfer performance of the shell-and-tube type preheater and required a smaller evaporator heat capacity, and the net power output and system thermal efficiency increased linearly in conjunction with the heat source temperature.

Patent documents contain critical research results that are valuable to the industrial, business, law, and policy-making communities [15]. Four major applications of patent information are listed as follows [16]: (1) analyzing competitors; (2) pretesting and tracking technology; (3) mastering crucial technology; and (4) identifying the trends and conditions of patent development in various national markets. Careful analysis of patent documents can assist in elucidating technological details and relationships, identifying business trends, inspiring novel industrial solutions, or developing investment policies [17]. In addition, Cantwell and Janne [18] indicated that using patent information would reduce research and development (R&D) time and costs by 60% and 40%, respectively. Patent analysis, which involves statistical, analytical, and comparative methods for examining information in patent documents, has been widely applied in studies examining R&D capacity, technological fields, industrial departments, and company levels [19].

Numerous research articles and documents have been published on the ORC. However, based on our research, no study has conducted a patent analysis of the ORC. Therefore, this study performed a statistical analysis of patent data to explore the technological developments of ORC systems. The evolution of numerous patents and assignees, technology life cycle, and major International Patent Classification (IPC) of the patent data were studied, and the patent data were analyzed based on country/office and assignee nationality. In addition, this study explored the top ten patent assignees and the trend of patent applications, patent families, and patent citations, and reviewed the top five patent families and five most frequently cited patents.

2. Methodology

Because the term “organic Rankine cycle” is an established term, this study used it as a keyword to search for patent data. When searching for patents from the United States Patent and Trademark Office, this study performed a keyword search for this term appearing in titles, abstracts, claims, or description/specification. When searching for patents from the World Intellectual Property Organization (WIPO) and European Patent Office (EPO), a “full text” keyword search was performed. Finally, when searching for patents from the Thomson Innovation (TI) commercial database, a keyword search was performed for the term appearing in titles, abstracts, or claims. These strategies covered a wide range of patent data that was beneficial to the statistical analysis. Table 1 shows a summary of the patent search results. Finally, this study

Table 1
Results of patent search from different databases.

Keyword: organic Rankine cycle	Number of patents
USPTO[a]	197 (issued) 415 (application)
WIPO[b]	239
EPO[b]	61
Thomson Innovation (TI)[c]	1026
TI with patent families integrating by the INPADOC	452
After screening the results of TI with patent families integrating by the INPADOC (present study)	304

[a] Keyword in title or abstract or claims or description/specification.
[b] Keyword in full text.
[c] Keyword in title or abstract or claims.

used patent data obtained from the TI database, which contains information on patents from various countries and offices, such as the US, United Kingdom (GB), France (FR), CN, Republic of Korea (KR), Japan (JP), EPO, WIPO, and International Patent Documentation Center (INPADOC). Initially, 1026 patents were obtained from the TI database. After organizing the data into patent families in accordance with the INPADOC, the research sample comprised 452 patents. Finally, after excluding patents unrelated to the ORC, the final research sample comprised 304 patents. The data were analyzed using Patent Map Analysis System (Industrial Technology Research Institute, Taiwan).

3. Results and discussion

3.1. Number of patents and assignees

Fig. 1(a) and (b) shows the evolution of the number of patents and assignees, respectively. The years presented in this figure, and in Figs. 5 and 6, are not continuous because no patent applications were filed in some years. Fig. 1 shows that the years that patent applications were filed are 1971, 1980, 1983, 1985, 1987–1992, 1995–1997, 1999, and 2001–2012. Moreover, the data on patents filed in 2012 were anticipated to continue increasing because the patent disclosure schedules limit the release of information. In general, when a patent is filed, the patent information is released approximately 18 months later. Fig. 1 shows that the growth rate of the number of patents and assignees was relatively low before 2006, with fewer than seven patents and six assignees observed for that year. However, the figure shows rapid growth in the number of patents and assignees in 2009–2011, indicating that ORC system technologies had begun receiving considerably more interest. Currently, many academic and research institutions are investing in R&D of ORC system technology. Furthermore, Fig. 2 shows that increasingly more ORC-based academic documents were published between 2003 and 2012. The figure shows that the number of academic documents published was increasing slowly leading up to 2009, and since the beginning of that year, the number of publications increased rapidly. The mean annual increase in the number of published documents is only 26 for the 2003–2008 period, whereas that of the 2009–2012 period is 167. The trend in the number of patent applications and published documents are relatively similar. Thus, 2009 can be considered an important year for ORC system development and patent applications.

3.2. Technology life cycle

Patent documents typically contain core technology information, and they can indicate the technology development and life

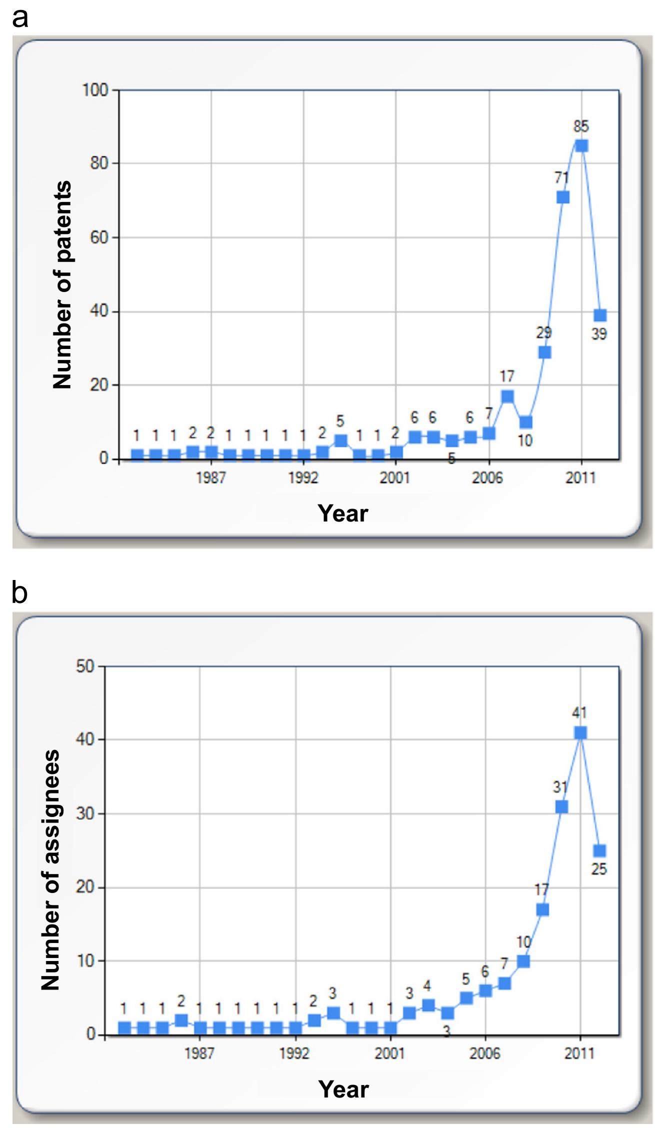

Fig. 1. Evolution of number of (a) patents and (b) assignees.

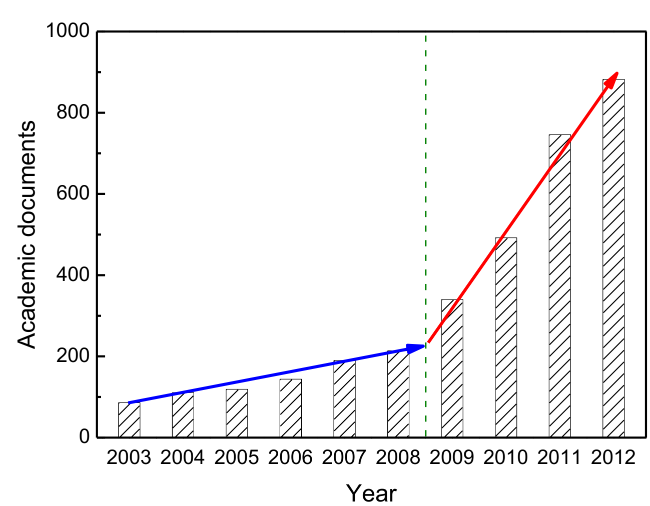

Fig. 2. Academic documents published in 2003–2012. The number of published documents were obtained from Google Scholar on August 23, 2013 (patent data were excluded).

cycle stage of a particular product before it is commercialized [20]. The technology life cycle comprises the following four stages [21]: (1) introductory; (2) growth; (3) maturity; and (4) decline. Fig. 3 shows the evolution of the number of patents relative to the assignees, which is a typical value for exploring the technology life cycle base on patent data. The figure shows that the number of patents and assignees increased gradually before 2006, indicating that the technology life cycle was in the introductory stage. This trend implies that few manufactures and institutions were investing in the R&D of ORC system technology before 2006. By contrast, Fig. 3 shows that the number of patents and assignees increased rapidly after 2006, particularly during the 2009–2012 period, indicating that the technology had entered the growth stage. Specifically, the number of patents (assignees) increased from 29 (17) in 2009 to 85 (41) in 2012. During the growth stage, fundamental technical problems are generally solved and market uncertainty is removed; moreover, many products are sufficiently developed for commercialization [21]. Currently, many ORC products, such as those manufactured by General Electric Company (US) and UTC Power Corporation (US), are commercially available.

3.3. International patent classification

The IPC system is a hierarchical system for classifying patents and utility models according to the area of technology to which they relate [22]. Fig. 4 shows the top ten IPCs based on the patent data examined in this study. Most patents were coded as F01K (200 patents), which is related to “steam engine plants; steam accumulators; engine plants not otherwise provided for; engines using special working fluids or cycles”. The next two codes are F03G (52 patents), which is related to “spring, weight, inertia or like motors; mechanical-power producing devices or mechanisms, not otherwise provided for or using energy sources not otherwise provided for”, and F01D (44 patents), which is related to “non-positive displacement machines or engines (e.g., steam turbines)”. These three codes account for most patents discussed in this study. In addition, these three codes are based on similar technical concepts (i.e., power generation) related to this study.

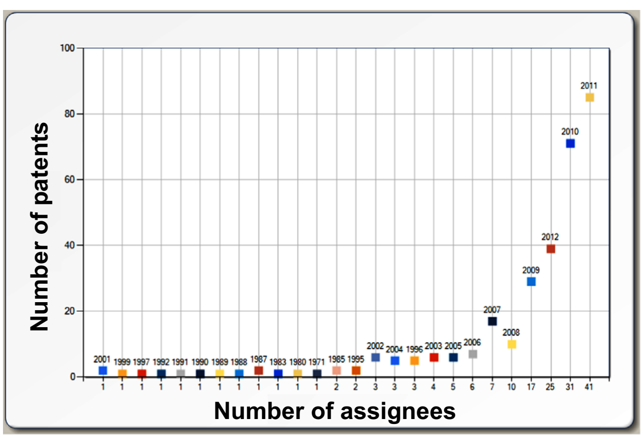

Fig. 3. Technology life cycle.

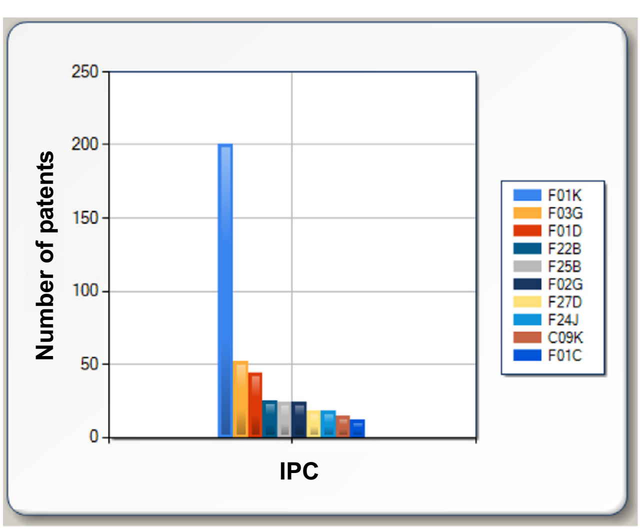

Fig. 4. International Patent Classification (IPC) of the patent data.

3.4. Analysis by country/office and assignee nationality

Fig. 5 shows the number of patents filed in various countries/offices, as well as the trend of the number of patent applications. Fig. 5(a) shows that CN, US, WO, KR, and CA are the top five countries/offices. The number of patent applications filed in CN is the highest, indicating that the ORC market in CN might offer the most potential for future development. Compared with other countries, the filing of ORC-related patents commenced only

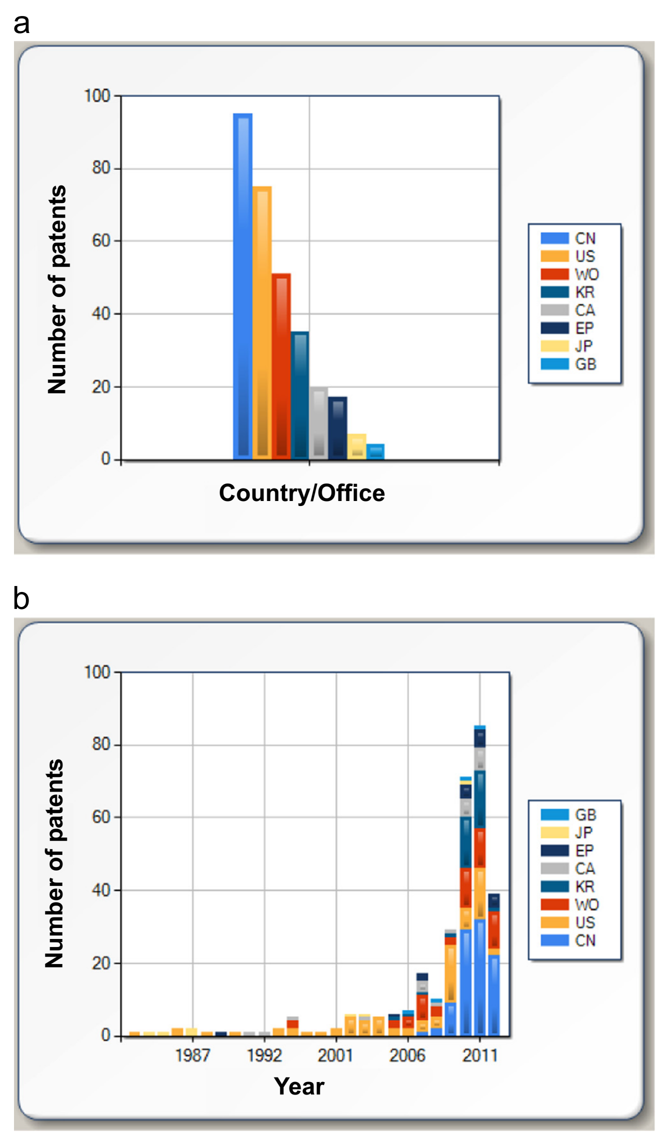

Fig. 5. Number of patents and its evolution by country/office. The initialisms “WO” and “EP” indicate that the patent was filed in the WIPO and EPO, respectively.

recently in CN, although the number of patent applications increased markedly in 2009–2012, as shown in Fig. 5(b). Subsequently, the number of patent applications in CN ranged from 20 to 30 for each year during the 2010–2012 period. Moreover, the filing of ORC-related patents commenced only recently in KR, also. By contrast, the ORC-related patents were filed earliest in US, and the number of patent applications increased gradually before 2009 and then peaked in 2009. These results explain the rapid increase in the number of patent applications after 2008 (Fig. 1).

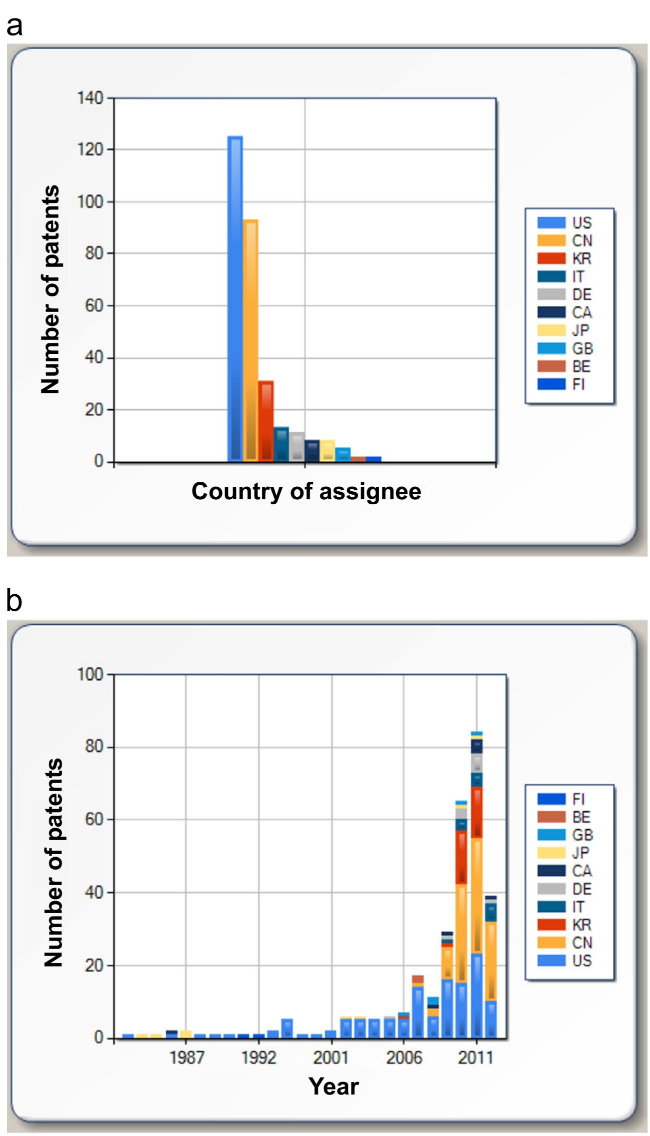

Fig. 6. Number of patents and its evolution by assignee nationalities.

Fig. 6(a) shows the total number of patent applications based on the nationality of assignees, and Fig. 6(b) shows the number of patent applications filed over time. Fig. 6(a) shows that the nationalities of the top five patent assignees are US, CN, KR, Italy (IT), and Germany (DE) are top five patent assignee's nationalities. Fig. 6(b) shows that US assignees were the first to file ORC-related patent applications, and the number of US applications continued to increase at a relatively steady rate. By contrast, CN assignees commenced filing ORC-related patent applications in 2007, and the number of applications increased rapidly since the beginning of 2009. In addition, since 2010, the number of patent applications filed by CN assignees is higher than that of US assignees.

3.5. Top ten patent assignees

Table 2 shows a summary of the top ten patent assignees. The table shows that all of top ten patent assignees are from the US, CN, and KR. In addition, the US assignees are all companies, whereas their CN and KR counterparts are mostly academic or research institutions. Moreover, these three US companies had already manufactured commercial ORC products.

The table also lists the patent families as well as the number of countries that the assignees filed patent applications in (patent families are detailed further in Section 3.6). The data show that the patent families increased monotonically in conjunction with the number of patent applications. The top two assignees, General Electric Company and UTC Power Corporation, respectively account for up to 83 and 76 patent families, which is considerably higher than that the other assignees. This marked difference occurred because they filed their patents in many countries/offices. By contrast, most of the CN and KR assignees generally filed patents only in their home countries; thus, the number of patents and patent families are similar.

Table 2 also lists the number of patent citations for the assignees (patent citations are detailed in Section 3.7). Patents filed by Ormat Technologies were cited the most frequently, with a mean of 10.6, which is considerably high compared with the other assignees. Table 3 shows the evolution of patent applications for the top 10 assignees. The table shows that patents filed by CN and KR assignees were rarely cited because they were filed only recently. Most of the top ten assignees filed most of their patent applications in recent years, particularly after 2008 (Table 3), which is why 2009 is an important year. Ormat Technologies and UTC Power Corporation filed most of their patent applications before 2009, which explains why these companies are the most-cited assignees. Moreover, the data in Table 3 show that General Electric Company is the most active assignee.

Because relatively few patent families are owned by CN and KR assignees, other assignees having many patent families are also

Table 2
Top 10 patent assignees.

Assignee (nationality)	Number of patents	Patent families	Number of application countries	Times cited (average)
General Electric Company (US)	31	83	11	81 (2.6)
UTC Power Corporation (US)	27	76	11	110 (4.1)
Korea Institute of Energy Research (KR)	25	25	2	0 (0)
Ormat Technologies (US)	19	19	4	201 (10.6)
Kunming University of Science and Technology (CN)	11	11	1	0 (0)
Tianjin University (CN)	9	10	1	0 (0)
Shanghai Weier Taike Screw Machinery (CN)	8	10	2	4 (0.5)
China Science and Technology University (CN)	7	8	1	7 (1)
Beijing University of Technology (CN)	7	7	1	0 (0)
Wuxi Guangyun Environmental Protection Machinery (CN)	7	7	1	0 (0)

Table 3
Evolution of patent application for top 10 assignees.

Assignee (number of active years)	~2008	2009	2010	2011	2012	Total
General Electric Company (6)	2	9	8	7	5	31
UTC Power Corporation (8)	24	–	3	–	–	27
Korea Institute of Energy Research (2)	–	–	15	10	–	25
Ormat Technologies (15)	16	2	–	1	–	19
Kunming University of Science and Technology (2)	–	–	5	6	–	11
Tianjin University (3)	–	4	1	–	4	9
Shanghai Weier Taike Screw Machinery (1)	–	–	8	–	–	8
China Science and Technology University (3)	1	2	4	–	–	7
Beijing University of Technology (3)	–	–	4	1	2	7
Wuxi Guangyun Environmental Protection Machinery (2)	–	–	1	6	–	7

Table 4
Other assignees with many patent families.

Assignee (nationality)	Number of patents	Patent families	Number of application countries	Times cited (average)
Chevron (US)	4	17	4	2 (0.5)
Energetix (GB)	3	17	7	0 (0)
3M Innovative Properties Company (US)	3	13	7	0 (0)
Nuovo Pignone (IT)	5	12	8	4 (0.8)
City University (GB)	2	11	7	3 (1.5)

surveyed in the present study. Table 4 shows that there are five institutions – Chevron (US), Energetix (GB), 3M Innovative Properties Company (US), Nuovo Pignone (IT), and City University (GB) – with more than ten patent families. The table data shows that all of these institutions are companies except for City University, and that Chevron, Energetix, and City University have patent families that are ranked as top-five patent families.

3.6. Top five patent families

A patent application can be filed in one or many countries, depending on the assignee's strategy. The first patent application is considered the priority application. A patent family is generally defined as a set of patents filed in various countries/offices to protect an invention; however, there are many definitions of patent family. Two of the most widely used definitions are detailed as follows. First, regarding simple patent families (i.e., patent equivalents), the EPO [23] states that “All documents having exactly the same priority or combination of priorities belong to one patent family.” Second, regarding extended patent families, the INPADOC [24] states that “All the documents directly or indirectly linked via a priority document belong to one patent family.” This study applied the extended patent family definition to analyze the patent data.

In general, there are five major uses of patent family data [25], detailed as follows: (1) to prevent double counting of one invention; (2) to suffer from a home bias and overestimate the patent propensity of residents because applicants are more likely to file an application in their home country first; (3) to forecast the number of patent applications to plan future resource requirements at patent offices; (4) to analyze the internationalization of technology markets; and (5) to study the economic value of patents, as well as the strategies employed by applicants. Moreover, Martínez [25] indicated that the INPADOC extended patent family definition provides an ideal basis for analyzing the various strategies employed by patent applicants, whereas the simple patent family definition is more restrictive, resulting in comparatively smaller patent families.

The top five patent families shown in Table 5 are briefly reviewed as follows. The first patent family, CA2694685A1 [26], proposed an ORC system composed of a turbine for driving a generator by using a gearbox fitted with an oil sump. While flowing through the oil sump, the oil can be heated rapidly without using a preheating process. The second patent family, GB2442743A [27], proposed a closed cycle heat transfer device composed of a boiler and condenser. The device can directly heat working fluid in an ORC system to ensure that the heat transfer device is free of noncondensable gases. Thus study observed four patents with an identical number of patent families; CA2694678A1 [28], CA2694682A1 [29], CA2812796A1 [30], and GB2457266A [31]. CA2694678A1 proposed a method and system for recovering oil from a turbine in an ORC system to prevent system failure, particularly during startup. The same assignee applied for patent CA2694682A1, which involves a methodical system for recovering oil from an evaporator in an ORC system. The recovered oil is returned to an oil sump for reuse in a turbine when required. CA2812796A1 explored heat recovery systems and methods, including a process for using heat byproducts (e.g., hot flue gas streams, high temperature reactors, steam generators, gas turbines, and diesel generators) to indirectly heat working fluid in an ORC system. GB2457266A proposed a method for generating power in the 20–500 kW by using medium-temperature heat sources with the range of 200–700 °C. This method involves using wet steam (even at low quality) to improve the efficiency in recovering power from such heat sources by condensing expanded steam in the boiler of an ORC system to increase the level of generated power. Table 6 details the patent numbers of these top five patent families.

This study observed that three patent families focused on the oil used in ORC systems. In general, oil is used to lubricate ORC systems, particularly the turbine bearings. However, the oil may combine with the working fluid and flow from the turbine to other system components, such as the condenser or evaporator. Most importantly, recovering oil from the condenser and evaporator is difficult; consequently, less oil is available for lubricating the turbine. In addition, oil accumulation in the condenser or evaporator can reduce the performance of the heat transfer process, which explains why many patent families have focused on researching the oil used in ORC systems.

3.7. Five most frequently cited patents

A patent receiving a high number of citations indicates that its practical value and importance is more than that of other patents [16]; furthermore, it indicates that the economic value and potential for earning profit is comparatively higher [32,33]. Therefore, this

Table 5
Top 5 patent families.

Patent number/assignee (nationality)	Title	Patent families
CA2694685A1 [26]/UTC Power Corporation (US)	Method and apparatus for starting a refrigerant system without preheating the oil	12
GB2442743A [27]/Energetix (GB)	A closed cycle heat transfer device	11
CA2694678A1 [28]/UTC Power Corporation (US)	Oil removal from a turbine of an organic Rankine cycle (ORC) system	10
CA2694682A1 [29]/UTC Power Corporation (US)	Oil recovery from an evaporator of an organic Rankine cycle (ORC) system	10
CA2812796A1 [30]/Chevron (US)	Utilization of process heat by-product	10
GB2457266A [31]/City University (GB)	Power generation from a heat source	10

Table 6
Other patent number of top 5 patent families.

Patent number	Patent numbers of families
CA2694685A1 [26]	AU2007357135A1; AU2007357135B2; CA2694685A1; CN101809379A; CN101809379B; EP2185872A1; JP2010534786A; JP4997333B2; MX2010001025A; NZ582891A; US2010205966A1; WO2009017474A1
GB2442743A [27]	CA2666321A1; CN101573564A; CN101573564B; EP2076717A2; GB0620201D0; GB2442743A; RU2009117668A; US2009211734A1; US8141362B2; WO2008044008A2; WO2008044008A3
CA2694678A1 [28]	AU2007357132A1; CA2694678A1; CN101765704A; EP2179145A1; JP2010534785A; JP4913904B2; MX2010001077A; NZ583259A; US2011005237A1; WO2009017471A1
CA2694682A1 [29]	MX2010001078A; US2010186410A1; WO2009017473A2; WO2009017473A3; AU2007357134A1; CA2694682A1; CN101970808A; EP2222939A2; JP2011503405A; JP5174905B2
CA2812796A1 [30]	AU2011311963A1; AU2011311966A1; CA2812796A1; CA2813420A1; US2012085095A1; US2012085097A1; WO2012048132A2; WO2012048132A3; WO2012048135A2; WO2012048135A3
GB2457266A [31]	CA2715063A1; CN101978139A; EP2262979A2; GB0802315D0; GB2457266A; GB2457266B; JP2011511209A; US2011048009A1; WO2009098471A2; WO2009098471A3

Table 7
Five most-cited patents.

Patent number/assignee (nationality)	Title	Times cited
US7124584B1 [35]/General Electric Company (US)	System and method for heat recovery from geothermal source of heat	65
WO2006069362A2 [36]/Honeywell International (US)	Stabilized iodocarbon compositions	58
US4942736A [37]/Ormat Technologies (US)	Method of and apparatus for producing power from solar energy	55
US6365289B1 [38]/General Motors Corporation (US)	Cogeneration system for a fuel cell	36
US20060010872A1 [39]/Honeywell International (US)	Working fluids for thermal energy conversion of waste heat from fuel cells using Rankine cycle systems	35

study reviewed the five most-cited patents (Table 7), which are discussed as follows. The number of citations listed in the table represents the number of times that patents were cited in other patents; an analysis of patent citations in research articles such as those published in Science Citation Index (SCI) journals is beyond the scope of this study. However, unexpectedly, only approximately 1.5% of the US patents were cited in SCI journals [34].

Table 7 shows that the most frequently cited patent, US7124584B2 [35], proposed a system and method for generating energy from geothermal heat sources. The proposed technique provides various benefits compared with conventional geothermal heat-recovery systems, such reduced drilling depths – which reduces the associated costs – and increased efficiency in extracting energy. WO2006069362A2 [36] proposed various iodocarbon-based compounds, such as trifluoroiodomethane, that are relatively stable and can be used in various applications, such as working fluids in ORC systems. US4942736A [37] presented a method and apparatus for generating power from solar heat, which is a potential application of the ORC. US6365289B1 [38] proposed a fuel cell system and process that involved using an ORC system to generate shaft work. The proposed system can be applied to convert thermal energy waste from fuel cell stacks into useful shaft work. Subsequently, the shaft work is used to compress and drive the working fluid (i.e., air) to the fuel cell stack. US20060010872A1 [39], which was filed by the same assignee who filed WO2006069362A2, proposed a novel type of working fluid that increases the cycle efficiency of ORC systems.

Two of five most frequently cited patents, WO2006069362A2 and US20060010872A1, are related to working fluids used in ORC systems. The performance of an ORC system is highly dependent on to the working fluid. Numerous studies, such as Bao and Zhao [5], Micheli et al. [6], Chen et al. [40], Rayegan and Tao [41], Wang et al. [42], and Heberle and Brüggemann [43], have researched methods for selecting the working fluid used in ORC systems. In general, selecting an appropriate working fluid involves multiple considerations [4], including environmental impact, safety, stability, pressure, availability, cost-efficiency, latent heat, molecular weight, low freezing point, and saturation curve.

4. Conclusion

This study analyzed patent data to explore the technological developments of ORC systems. The patent data were obtained from the TI commercial database, which contains patent information from many countries (e.g., US, GB, FR, CN, KR, and JP) and offices (e.g., EPO, WIPO, and INPADOC). After querying, filtering, and organizing the search results into patent families in accordance with the INPADOC, this study analyzed 304 OCR-related patents. The primary findings of this study are detailed as follows.

1. Patent applications increased gradually before 2006. The marked increase in 2009–2011 primarily resulted from the increased number of patent applications filed in CN and KR. This study shows that 2009 is an important year regarding developments in ORC systems and patent applications.

2. Three main IPCs of the obtained patent data are F01K, F03G, and F01D. The technical concepts associated with these three codes are essentially related to generating power, which is highly relevant to this study.
3. US assignees were the most prominent assignees, although the most patent applications were filed in CN, indicating that the market for ORC systems in CN might offer the most potential for future development.
4. All of the top ten assignees were from either the US, CN, or KR. The US assignees are all companies, whereas most of their CN and KR counterparts are academic or research institutions.
5. The top two assignees, General Electric Company and UTC Power Corporation, respectively account for up to 83 and 76 patent families, which is considerably more than the other assignees. By contrast, most of the CN and KR assignees generally filed patents only in their home country; thus, the number of patents and patent families are similar.
6. Patents filed by Ormat Technologies were cited the most frequently, with a mean of 10.6, which is considerably high compared with the other assignees. The patents filed by CN and KR assignees were rarely cited because they were filed only recently.
7. Most of the top ten assignees filed their patent applications in recent years, particularly after 2008. Currently, the most active assignee is General Electric Company (US).
8. The top five patent families are CA2694685A1, GB2442743A, CA2694678A1, CA2694682A1, CA2812796A1, and GB2457266A. The five most frequently cited patents are US7124584B2, WO2006069362A2, US4942736A, US6365289B1, and US200600 10872A1. This study shows that three patent families focus specifically on oils in ORC systems, and two of the five most frequently cited patents have proposed working fluids for ORC systems.
9. Based on the analysis results of this study, the technology life-cycle status of the ORC is currently in the growth stage, indicating that many products are sufficiently developed for commercialization [21].

Future studies should consider evaluating the current state of technology developments in a specific field to identify application areas for new patents. Such research should focus on identifying R&D trends to assist in predicting where novel and crucial innovations are likely to occur.

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